Effect of Aluminum-Induced Gettering and Backside Surface Field on the Efficiency of Silicon Solar Cells

P. S. Plekhanov, M. D. Negoita, and T.Y. Tan
Department of Mechanical Engineering and Materials Science
Duke University
Durham, NC 27708-0300

ABSTRACT

In silicon solar cell fabrication, impurity gettering by an aluminum layer and indiffusion of Al for creating the back surface field (BSF) are inherently carried out in the same process. We modeled these two processes and analyzed their impact on solar cell efficiency. The output of gettering and Al indiffusion modeling is used as an input for calculation of solar cell efficiency. The efficiency gain is obtained as a function of the processes duration. To check the relative contributions of gettering and BSF in improving the efficiency, their effects are evaluated together and separately. It is found that, for solar cells fabricated from low quality, multicrystalline Si, the efficiency gain is solely due to gettering. In solar cells made of high quality Si, the efficiency gain is primarily due to gettering, but the BSF may play a significant role if the cell thickness is less than about 200 μm. The model provides a means for optimization of the temperature regime for both processes and maximization of solar cell efficiency.

I. Introduction

High quality Si substrates with long minority carrier lifetime and diffusion length must be used to obtain high efficiency crystalline silicon solar cells. On the other hand, in order to minimize the cost of the cells, it is desirable to use cheap multicrystalline Si substrates. Crystal imperfections and impurities, such as Fe, Cu, Ni, and other transition metals, contained in these substrates in high concentrations, are charge carrier recombination centers, which significantly reduce the efficiency of solar cells. Gettering by an Al layer consists in deposition of Al on the wafer surface and annealing at temperatures of 700 to 1200 ºC. Since transition metals have much higher solubilities in Al than in Si, they outdiffuse from the Si substrate into the Al layer and remain there, outside of the device active region. In practice, during gettering, indiffusion of Al into Si also occurs. Since aluminum is a p-type dopant, its indiffusion creates a gradient of p-dopant concentration near the back surface in cells with a p-type base, giving rise to the back surface field (BSF). The BSF provides an additional driving force for the diffusion of electrons towards the front surface. In order to optimize the process of Al gettering and indiffusion to obtain maximum efficiency enhancement due to both gettering and BSF, a model incorporating both of these processes has been developed.

II. Physical Model

In order to see how gettering and Al indiffusion influence the resulting cell performance, the process model was combined with solar cell device model, which predicts the efficiency of the resulting cell. Both Al concentration and minority carrier recombination rate as functions of depth are used as input data for the cell modeling.

II.1. Impurity Electrical Activity Modeling

The cell efficiency is calculated based on impurity concentration and precipitate size profiles. For dissolved impurity atoms, the measured values of the minority carrier capture cross-section were used [1]. For precipitates, the capture cross-section was calculated as a function of precipitate size, concentration, Schottky barrier height between the precipitate and Si, Si matrix dopant concentration, and carrier generation rate. The method of this calculation is described elsewhere [2].

II.2 Process Modeling

A detailed description of modeling the gettering process by an Al layer applied to dissolved and precipitated impurities in Si has been given elsewhere [3]. An Al layer on the Si wafer surface provides gettering effect due to chemical segregation. The model applies to the precipitate growth as well as dissolution processes. Solution of this system of equations provides impurity concentration and precipitate size profiles at any instant during the gettering process. Al indiffusion (and hence, p-doping) depth profiles can be obtained straightforwardly as a solution of the diffusion equations.

II.3 Solar Cell Efficiency Calculation

A solar cell was treated as a p-doped base and n-doped emitter with an abrupt p-n junction. In each layer, the majority carrier concentration was assumed to be constant, and the variation of only minority carrier concentration was considered, since under typical illumination conditions of 1 sun, the carrier generation is weak. Steady-state semiconductor equations have been solved in the p-type base and n-type emitter with the corresponding boundary conditions depending on the external devices parameter V, the photovoltage across junction. The maximum of output power and efficiency has been found by varying V and calculating j the corresponding total carrier flux through the junction and then searching for the maximum of their product.

III. Numerical Simulation

To calculate the solar cell efficiency change as a function of Al treatment time, a computer program has been developed using the process and device model equations discussed above. The output of the process simulation is used as an input for device modeling. Al gettering affects minority carrier recombination throughout the wafer, and Al indiffusion creates BSF and affects Auger recombination near the backside. Two types of wafers were considered, low quality and high quality. In this study, Fe was used as a sample impurity. Wafers of the first, high quality type (e.g. dislocation-free electronic grade Si) are saturated with Fe at 700 ºC and contain no precipitates. In the wafers of the second, low quality type (e.g. multicrystalline with high concentration of defects, high Fe concentration, and FeSi precipitates) Si is saturated with Fe at 1100 ºC. The thermal equilibrium between the solution of Fe in Si and FeSi precipitates is reached at 700 ºC.

IV. Results and Discussion

Results of the modeling are shown in Table I and Figures 1 and 2.

Substrate quality, base doping	Efficiency gain due to BSF	Efficiency gain due to gettering	Efficiency gain due to BSF and gettering	Gain due to synergism
High quality, optimum base doping	0.005	0.35	0.38	0.02
High quality, low base doping	0.047	0.47	0.58	0.06
High quality, high base doping	0	0.14	0.14	0
Low quality, optimum base doping	0	2.67	2.67	0.001

Table I. Original efficiency and efficiency gain (%, absolute) due to Al gettering and BSF for high and low quality Si solar cells.

Whereas gettering increases carrier diffusion length in the base bulk, the BSF reduces effective back surface recombination velocity and provides an additional driving force for the diffusion of minority carriers from the vicinity of the back surface towards the p-n junction. If the base thickness is significantly smaller than the minority carrier diffusion length, minority carriers generated near the back surface are likely to reach the p-n junction without recombining in the bulk. Then a reduction of the back surface recombination will result in an increase of the number of carriers collected at the p-n junction and higher cell efficiency as it happens in high quality Si, especially after gettering. At the same time, any further reduction of the bulk recombination will have little effect on the cell efficiency. On the other hand, if the base thickness is significantly larger than the minority carrier diffusion length, the recombination of minority carriers occurs mostly in the bulk, and only a small fraction of minority carriers reaches the p-n junction from the vicinity of the back surface. In this situation, a decrease of the back surface recombination velocity affects the collection of minority carriers at the p-n junction very little, and the BSF benefit is small as it happens in low quality Si. The role of gettering, on the contrary, is significant, since any increase of the minority carrier diffusion length in the base bulk directly affects the collection of carriers at the p-n junction. Thus, the larger is the cell thickness, the greater is the role of gettering and the smaller is the role of BSF in improving the cell efficiency. These conclusions are illustrated in Figures 1 and 2, where the calculated efficiency gain is plotted versus thickness for high and low quality Si cells, respectively.

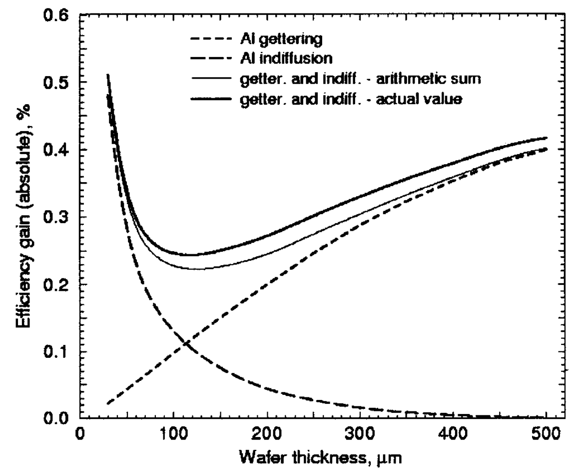

Fig. 1 Calculated high quality Si solar cell efficiency gain due to Al gettering and indiffusion as a function of wafer thickness. Process duration 10^4 s, process temperature 1000ºC.

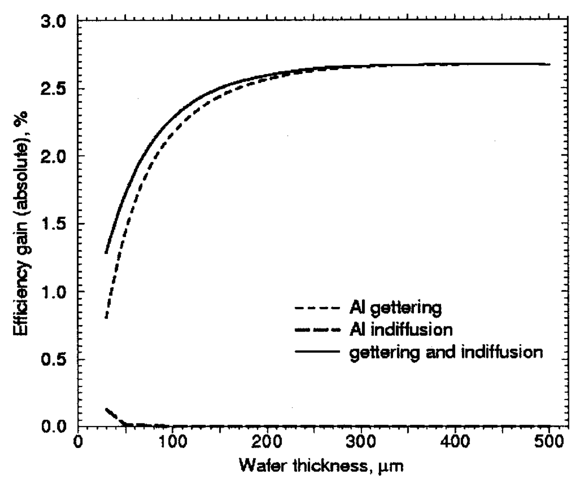

Fig. 2 Calculated low quality Si solar cell efficiency gain due to Al gettering and indiffusion as a function of wafer thickness. Process duration 10^4 s, process temperature 1000ºC.

References

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